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QUALITY-BASED PRICE DISCRIMINATION AND TAX INCIDENCE
EVIDENCE FROM GASOLINE AND DIESEL CARS

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Quality-based Price Discrimination and Tax Incidence

— Evidence from Gasoline and Diesel Cars

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Abstract

The existing tax policies towards gasoline and diesel cars in European countries provide a unique opportunity to analyze quality-based price discrimination and the implied tax incidence. We develop an econometric framework for the demand and pricing of gasoline and diesel cars. Consumers choose the type of engine based on their annual mileage; prices are set by the manufacturers. Our empirical results show that the relative pricing of gasoline and diesel cars is consistent with price discrimination of a monopolistic type, effectively segmenting low mileage from high mileage consumers. On average, about 75 to 90 percent of the price differentials between gasoline and diesel cars can be explained by markup differences. The implied tax incidence is especially based on fuel taxes and less so on annual car taxes. Implications for the effectiveness of tax policy are drawn.

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1 Introduction

Price discrimination based on willingness to pay for quality has been studied extensively in the theoretical literature. Mussa and Rosen (1978) show how a monopolist can extract higher profit margins from consumers with a higher willingness to pay for quality by offering a wide product line of price-quality combinations. When several firms compete, the feasibility and the nature of quality-based price discrimination is less well understood. It depends on the precise pattern of competitive interaction, and no general results are available.[1] At the same time, efforts to quantify the empirical importance of price discriminating practices have been limited. The problem is, of course, that observed price differentials between high and low quality variants may stem from either cost or markup differences.

In the European car market a unique opportunity is available to empirically analyze quality-based price discrimination. In most European countries, cars are sold under two types of engine: the gasoline and the diesel engine. The diesel engine has a higher "quality" in the sense that it consumes less fuel per mile and requires less expensive fuel due to a favorable tax treatment. Consumers differ in their willingnes to pay for this quality aspect since they are heterogeneous in their annual mileage. As a result, manufacturers may consider a price discriminating strategy by charging different profit markups on the gasoline and the diesel variants to exploit the consumer mileage heterogeneity.

We develop an econometric model of demand and pricing for gasoline and diesel cars. The demand estimates show that the heterogeneity in the consumers' annual mileage is central in explaining the gasoline/diesel market shares. In particular, the demand model predicts average mileages for gasoline and diesel consumers that are consistent with prior information. The pricing model decomposes the observed price differentials between gasoline and diesel

[1] See, for example, the specific assumptions on brand preferences used in Katz (1984) to model product differentiation and competitive interaction. Gilbert and Matutes (1993) use a different model of brand preferences, and find, surprisingly, that competition eliminates the feasibility of quality-based price discrimination. The theoretical difficulties in analyzing quality-based price discrimination with competing firms are more generally present in screening models of second-degree price discrimination, see Armstrong and Vickers (2001).

cars into their cost and markup components. The estimates demonstrate that the price differentials are best explained by price discrimination of a monopolistic type. On average, about 75 to 90 percent of the price premium to be paid for a diesel car can be attributed to price discrimination between high and low mileage consumers; the remaining part follows from higher costs due to differences in specifications. These results empirically demonstrate the feasibility and the importance of quality-based price discrimination in the presence of competition. The results have important implications for the effectiveness of fuel tax and car tax policy. For example, the estimated demand effect of an increase in the diesel fuel tax is reduced by 50 percent if one properly accounts for the manufacturers' pricing responses to tax changes. The results also imply that raising diesel fuel or car taxes would unambiguously increase tax revenues, whereas the revenue effects of raising gasoline taxes are mixed.

As noted above, there exists very little econometric evidence on quality-based price discrimination. Shepard (1991) exploits a natural experiment in which firms differ in their ability to price discriminate, but presumably not (much) in their cost of production. Observed differences between firms in price differentials may then be attributed to markups, i.e. price discrimination.[2] Unlike Shepard's application, we have no prior information on costs. We instead infer the presence of price discrimination from the structural model of conduct that is found to best fit the data. Leslie (1999) considers various types price discrimination for a Broadway play, including price discrimination based on different seat qualities. He starts by estimating the demand system, and computes the prices as predicted by the current industry circumstances. He then investigates how prices would change if the firm had more flexibility in setting the price menu.[3]

[2]In particular, Shepard (1991) considers price differentials between full-service and self-service at gasoline stations. She compares these differentials between stations offering both types and stations offering only one type of service. Assuming that there is no difference in the cost of offering these services combined rather than separately, one may attribute higher price differentials at multi-service stations to price discrimination. Cohen (2001) adopts similar types of reduced form tests in the market for paper towels.

[3]Metrick and Zeckhauser (1996) also consider the relationship between prices and quality (as well as quantity), in a theoretical and empirical analysis. In their application, different firms sell different qualities, and the question is whether prices will differ between these differentiated firms (or whether instead sales will

Research on demand and pricing in the automobile market has received considerable attention in recent years. Most contributions ignore the issue of quality-based price discrimination by limiting attention to *base* model cars. The focus is instead on the nature of product differentiation and competition between different car models. See the contributions by Bresnahan (1981, 1987), Berry, Levinsohn and Pakes (1995, 1999), Feenstra and Levinsohn (1995), Goldberg (1995), and Petrin (1999) for the U.S. market.[4] Regarding the European car market, Verboven (1996) and Goldberg and Verboven (2001) have provided evidence of international price discrimination. This is price discrimination of the third degree, and is achieved by the manufacturers' strategies to prevent cross-border consumer (or parallel importer) trade. The present paper may be seen as reinforcing the evidence that firms in a seemingly competitive market succeed in price discrimination strategies, also of the second degree type, by profitably segmenting consumers with a low annual mileage from those with a high annual mileage.

There exists very detailed econometric evidence on price elasticities of demand for fuel. Goodwin (1992) and Oum, Waters and Yong (1992) provide a survey of this literature. The considerable amount of empirical research can be explained by the strong interest from a public policy taxation perspective. A distinction is usually made between short-term and long-term fuel price elasticities. Short-term elasticities measure fuel demand effects keeping the vehicle stock fixed; long-term elasticities take into account changes in the size and the structure of the vehicle stock in response to fuel price changes.[5] A robust finding is that

differ). In our paper, the *same* firm offers different qualities (gasoline versus diesel), a central question being whether that firm can use its different qualities to price discriminate.

[4]Among these product differentiation studies, Bresnahan (1987), Feenstra and Levinsohn (1995) and Berry, Levinsohn and Pakes (1999) consider the nature of competition.

[5]The long-term changes in the size and structure of the vehicle stock may follow from both changed car purchasing decisions and from new model introductions. Pakes et al. (1993) provide convincing evidence (partly based on patent data for combustion engines) that companies in the U.S. started to develop more fuel efficient cars in response to the rise in fuel prices in 1973; the development of reliable diesel cars in Europe during the 70s and 80s has also been a response to fuel prices, as seen below. In our econometric analysis we nevertheless take the product characteristics as given. The long term elasticities then essentially differ from the short term elasticities because of changed car purchasing decisions, in particular the substitution

the long-term fuel price elasticities are substantially higher than the short-term elasticities. The results of the present paper imply that the long-term fuel price elasticities may be considerably overestimated (with a factor of more than 2) if one does not properly account for the observed tax incidence by the car manufacturers in response to fuel price changes.[6]

The outline of the paper is as follows. The next section describes the market for gasoline and diesel cars in three European countries: Belgium, France and Italy. Section 3 introduces the econometric model of gasoline/diesel demand and pricing. Section 4 presents the empirical results. Section 5 concludes.

2 The market for gasoline and diesel cars in Europe

The vast majority of automobile engines in Europe are fuelled with either gasoline or diesel petroleum.[7] Automobiles with a diesel engine quickly gained popularity in Europe during the seventies, stimulated by a favourable tax treatment and the subsequent technological improvements. In recent years, the choice between a gasoline or a diesel car has become one of the key elements in the European consumer's car purchasing decision.

To introduce the questions we address in this paper, we have a first look at the technology, taxation, pricing and demand. This discussion will be based on the data set we collected for three European countries, which is summarized in Table 1A and 1B. The data consist of sales, list prices, taxes and technical characteristics of 41 pairs of automobile models in Belgium, France and Italy during 1991-1994. These data are supplemented with information on the distribution of annual car mileage.[8] The included models are the base models from

to diesel engines with a lower cost per mile.

[6]Issues of tax incidence are also present in Fershtman, Gandal and Markovich' (1998) empirical study of the Israeli car market, with an instructive policy simulation analysis of alternative taxes. They only consider car taxes, and do not look at taxes in related complementary markets, such as fuel taxes. Furthermore, their empirical estimates do not establish that firms indeed take into account taxes in their pricing strategies; the extent of tax incidence is driven by their assumption of Bertrand pricing behavior.

[7]There is a third possible fuel: liquid patrol gas (LPG). However, the market share of automobiles with an LPG engine is quite small, and in fact negligable in the three European countries that we study in detail.

[8]Data on list prices (including value added taxes) and technical characteristics come from the follow-

the gasoline and the diesel range. In cases where the base model of a gasoline variant was equipped with a different set of options than the diesel variant (e.g. air conditioner or ABS), we appropriately upgraded or downgraded the variants such that they contain the same equipment.[9] Table 1A shows summary statistics for the separate gasoline and diesel variables. Table 1B shows more detailed summary statistics for the *differences* between the diesel and gasoline variables, which are the actual variables entering in the empirical model. The "between" standard deviation measures the standard deviation due to variation across models, whereas the "within" standard deviation is a measure of the variation across the three countries. The standard deviations show that the technical characteristics especially show variation across models; the tax variables (fuel and car tax) mainly show variation across countries; and the initial purchase price and sales variables show important variation over both dimensions.

Technology

In a gasoline engine, a mixture of air and fuel is ignited by a spark; in a diesel engine, the mixture explodes spontaneously due to the high pressure. These technical differences lie at the basis of some well-known differences in performance and comfort. The diesel engine traditionally produced lower horsepower (at equal engine size), and lower speed and acceleration than the gasoline engine. Furthermore, the diesel engine has a reputation of making more noise and of a less reliable start under cold temperatures. On the positive side, a diesel engine generally has a greater fuel efficiency yielding a greater "autonomy" (the number of miles that can be driven with a full tank). Diesel engines also have a longer durability than their gasoline counterparts.

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ing weekly retail catalogues (August issue) *De Autogids* (Belgium), *l'Automobile Magazine* (France), *Quattroruote* (Italy). Sales data come from publications on new car registrations by the *Nationaal Instituut voor Statistiek* (Belgium), *l'Argus de l'Automobile et Locomotions* (France) and *A.C.I.* (Italy). Average annual gasoline and diesel fuel prices, for all three countries, are taken from *l'Argus de l'Automobile et Locomotions.* Data on the distribution of mileage, by several principle characteristics, come from the industry associations, A.C.E.A., F.E.B.I.A.C. and from survey data by De Borger (1987) and C.B.S.

[9]Helpful and competent research assistance in this tedious data collection process was provided by Sandy Torrekens.

Due to technological improvements (such as the introduction of the turbo and direct injection), these differences have diminished in recent years. Manufacturers in fact spend significant efforts to offer closely comparable "twin models": for each model, they typically offer about 4 to 6 different versions of gasoline engines, and a similar number of diesel engines. The averages in Table 1A and 1B give an idea of the current differences in technical characteristics. The lower engine power of diesel cars (horsepower, speed, acceleration time) is compensated by the higher engine capacity (displacement) and a higher weight (partly due to a stronger insulation against the diesel noise). Greater diesel fuel efficiency is reflected in the lower amount of liter consumed per 100 km.

Taxation

It is hard to overstate the importance of taxes on automobiles in Europe. In France and Belgium, automobile-related tax revenues respectively amounted to about 800 and 1000 dollars per capita in 1997.[10] In other European countries, similar amounts apply. The most important taxes are value added taxes on the purchase of a (new or second-hand) car, annual car taxes, and excise taxes on fuel. The annual car taxes and the fuel taxes have been designed to follow a discriminatory policy towards gasoline and diesel cars. Furthermore, different countries typically adopted different policies. Table 2 illustrates this for the countries of our data set. The first three rows present the *average annual fuel costs*, i.e. price per liter times liters per mile times annual mileage for the average driver. These fuel costs consist of about 70% excise taxes. In all three countries, the average person driving a gasoline car spends about 1100 dollars per year on fuel. In Belgium and Italy, about 400 dollars per year can be saved on fuel from driving a diesel car; in France, the average savings are even 500 dollars per year. The next three rows on Table 2 present the *annual car taxes*, which are based on the fiscal horsepower assigned to a car. In France, the annual car taxes also favor diesel cars. In Belgium but especially in Italy, the annual car taxes on diesel cars are higher than on gasoline cars. In Italy, the higher annual car taxes even outweigh the savings in fuel costs from driving a diesel, at least for the average Italian driver.

The policy reasons behind the differential tax treatment towards gasoline and diesel cars

[10]These numbers are from CCFA and FEBIAC, the French and Belgian automobile associations.

are not obvious. According to the OECD (1993, p. 210), the favorable tax treatment on the diesel fuel "is intended to avoid disabling freight transport, but governments also see some value in the introduction of diesel cars". For example, the OECD attributes the particularly favorable attitude towards diesel cars in France to the strength of French manufacturers in exporting diesel cars and supplying engines to other manufacturers; it also reflects a more general concern in French energy policy to minimize oil dependence (since diesel cars consume less). From an environmental perspective, the favorable diesel tax treatment does not seem justified. As discussed for example in Michaelis (1995), the diesel engine emits less carbon monoxide than the (unleaded) gasoline engine, roughly the same volatile organic compounds, and more NO_x. In addition, it emits airborne particulates unlike the gasoline engine. The net result of these different emissions is that diesel cars are not clearly less damaging from an environmental (e.g. global warming) point of view, whereas they do have some clear disadvantages from the point of view of urban air quality (Crawford and Smith, 1995). From an economic point of view, a favorable diesel tax treatment may be defended by Diamond and Mirrlees' (1971) rule that intermediate goods (i.e. the transportation sector) should not be subject to revenue-raising taxes. However, such a reasoning no longer seems valid in current times, since the boundary between the diesel and gasoline fuel no longer closely corresponds to the boundary between intermediate goods (truck) and final goods (cars) consumption.[11]

Demand

Whatever the motives behind the discriminatory tax practices, a comparison across the three countries suggests that consumers have taken the taxes into account in their car purchasing decisions. This can be seen from the "dieselization rate", i.e. the percentage of diesel cars in the total car sales, as shown in Table 2. In Belgium and especially in France, where diesel cars have a very favorable tax treatment, the dieselization rate is high. In Italy, where

[11]This used to be different one decade ago, when most diesel usage originated from truck traffic, as is still the case in the U.S. market. Note also that one could in principle implement Diamond and Mirrlees rule in an alternative way, by allowing tax deductions for fuel or car usage to business users. This is the case in several countries.

the annual fuel cost savings must be balanced against a significantly higher annual diesel car tax, the dieselization rate only reaches 15 percent.

The consumer's annual mileage is a main driving factor in her gasoline/diesel car purchasing decision. Most European car magazines carefully guide their customers by periodically publishing detailed tables to compare the cost of gasoline and diesel cars under alternative mileage scenario's.[12] More recently, internet websites allow consumers to compute their costs for gasoline and diesel cars by entering their expected mileage. The importance of the consumer's annual mileage is reflected in the data. In Belgium, for example, the average annual mileage for diesel car users amounts to 25000 km, compared to an annual mileage of only 14300 km for gasoline car users.[13]

Pricing

To which extent have the firms taken the discriminatory tax policies into account in their pricing strategies? The average price data in Table 2 provide a preliminary answer to this question. In all three countries, diesel cars are more expensive than gasoline cars.[14] The question is, of course, whether these higher prices are caused by higher (marginal) costs or by higher markups. The empirical model in the next sections aims to address this question. At this point, observe that the price premium for diesel cars is much higher in France than in Belgium and in Italy. Given that the most favorable tax treatment for diesel cars is in France (and assuming that diesel cars are no more costly to sell in France than elsewhere), this indicates that price differentials between gasoline and diesel cars are at least partly driven by markups.

Another way to verify whether the car prices reflect the tax policies is by considering a simple reduced form regression. Table 3 regresses the car price differential between diesel and gasoline cars on differences in observed technical characteristics and on the differences

[12]For example, for a large set of cars consumer magazine Test-Achats (1995, nr. 373) even computed the critical mileages above which the diesel variant becomes more advantageous than the gasoline variant.

[13]See De Borger (1987). A Figure reported by Transport Research Laboratory (1995) indicates comparable mileage differences between gasoline and diesel cars for most European countries.

[14]This remains true after adjusting for differences in observed quality. This was verified in a hedonic regression from which quality-adjusted price differences may be computed.

in average annual fuel cost and car tax differentials.[15] In the first specification (column 1) the fuel cost and annual car tax differential enter linearly. The estimates show that a firm raises the price premium for a diesel car by 6.34$ in response to an additional annual fuel cost saving of 1$ from purchasing of a diesel car. Firms do not appear to significantly change their diesel price premium in response to a change in the annual car tax difference. In the second specification (column 2 of Table 3) the square of fuel cost and annual car tax also enter, to allow for a nonlinear relationship. Additional annual fuel cost savings on diesel cars again lead to higher diesel price premia, though the effect is declining; at an average annual fuel cost saving of 456$, a firm would raise the diesel price premium by 10.17$ in response to an additional annual fuel cost saving by 1$. A decrease in the annual car tax difference would lead to an increase in the diesel price premium by 3.09$ at a zero tax difference, but only to an insignificant 1.92$ increase evaluate at the average car tax difference of 112$. Overall, these regressions suggest that firms substantially adjust the diesel price premium in response to fuel cost differentials, but less so in response to car tax differentials.

The above discussion gave some descriptive evidence on how tax policies may influence both consumer demand and manufacturer pricing behavior. This is now formalized in a model to explain price differentials, and decompose them into marginal cost and markup differences.

3 Consumer demand

3.1 The model

Consumers choose to purchase one particular car make j coming with one of two engine variants k, where $k = G, D$ refers to the gasoline or the diesel engine. The utility derived from purchasing one particular make/engine variant takes the following simple form

[15]These regressions resemble standard "hedonic regressions", except that now prices are expressed in differences between diesel and gasoline cars, hence the lower R^2. The regressions should only be interpreted as preliminary evidence, since they contain a mixture of both suply side and demand side considerations.

$$u_{jk} = z + a_{jk} + \nu_j,$$

where a_{jk} is the mean intrinsic utility from purchasing make j with engine k, common to all consumers; ν_j is an individual-specific random component around that mean; and z is the consumption of goods other than car services. Both the mean utility term a_{jk} and the individual-specific term ν_j may depend on observable characteristics such as performance, size and safety. The term ν_j is often modelled as an i.i.d. random variable (as in the logit model), implying no correlation of consumer preferences across cars. Advances in the discrete choice literature, most notably by Berry (1994) and Berry, Levinsohn and Pakes (1995), show how to relax this unrealistic assumption and allow consumer preferences to be correlated across cars with similar characteristics. Their random coefficients specification of ν_j yields a flexible aggregate model of product differentiation, with plausible substitution patterns between different cars. For recent applications see, for example, Nevo (2001) and Petrin (1999). As shown below, in our application no specific structure is imposed on ν_j. We focus instead on the choice of engine, conditional on the car choice.

Consumers have an annual income y to be spent on car services and other goods z. Annual expenditures on car services include the following three terms: an annualized initial purchase price, annual car taxes and annual fuel expenditures.

(i) The purchase price of a car is p_{jk}. This is written in annualized terms as ρp_{jk}, where ρ is an annualization coefficient, depending on the consumer's rate of time preference (or implicit interest rate) and the expected vehicle life.[16] When consumers have a high implicit interest rate or when the expected vehicle life is low, ρ is close to one and the purchase price of a car is quickly discounted. Conversely, when consumers have a low implicit interest rate, ρ is close to zero.

[16]Following Hausman (1978), one may define the annualization coefficient as $\rho = (r/(1+r)\left(1-(1+r)^{-T}\right)^{-1}$, where r is the rate of time preference (implicit interest rate) and T is the vehicle life. From the estimate of ρ and information on T one can then infer the implicit interest rate r.

(ii) In addition to the annualized purchase price ρp_{jk}, the consumers also need to pay an annual car tax of τ_{jk}. This tax may differ across makes and variants, and is usually based on the "fiscal horsepower" of a car. The fiscal horsepower is computed from characteristics such as horsepower, displacement and weight according to a formula defined by the government.

(iii) Finally, consumers incur annual fuel expenditures. These depend on the fuel price q_k for fuel k (i.e. gasoline or diesel fuel, in dollars per liter), on the fuel efficiency w_{jk} (in liters per 100 kilometer), and on the annual mileage θ. Annual fuel expenditures per mile are $\pi_{jk} = q_k w_{jk}$. The annual mileage θ is a random variable which may vary from consumer to consumer. For simplicity, assume that annual mileage is not sensitive to fuel prices (inelastic demand), so that a consumer's total annual fuel expenditures equal $\pi_{jk}\theta$.[17]

In sum, when purchasing a particular make j with engine k, total annual expenditures on car services are given by $\rho p_{jk} + \tau_{jk} + \pi_{jk}\theta$. The remaining income $y - \rho p_{jk} - \tau_{jk} - \pi_{jk}\theta$ is left for the consumption on other goods z (at a price normalized to 1). We can then write a consumer's indirect utility from purchasing a make j with engine k as

$$u_{jk} = y - \rho p_{jk} - \tau_{jk} - \pi_{jk}\theta + a_{jk} + \nu_j. \tag{1}$$

Given this indirect utility function, consumers can choose their most preferred make and engine variant. For our purposes it is sufficient to focus on the consumer's choice of engine variant k *conditional* on purchasing a particular make j. This choice crucially depends on the consumer's annual mileage θ. A consumer is indifferent between buying make j with a gasoline engine G and with a diesel engine D if $u_{jG} = u_{jD}$, hence if her annual mileage equals

$$\theta = \theta_j^* \equiv \frac{\Delta a_j - \rho \Delta p_j - \Delta \tau_j}{\Delta \pi_j}, \tag{2}$$

[17]Previous studies have estimated quite low "short-term" elasticities of gasoline demand, varying from 0 to around $-.2$. See for example Goldberg (1998) for a discussion.

where the Δx_j denotes the difference between a diesel and a gasoline variable, i.e. $\Delta x_j \equiv x_{jD} - x_{jG}$. Consumers driving $\theta < \theta_j^*$ prefer the gasoline engine of j; other consumers prefer the diesel engine of j. One can then compute the probability that the gasoline variant is chosen, *conditional* upon buying j, and equate this to the observed market share of the gasoline variant of j in the total sales of j, $s_{G|j}$, i.e.

$$s_{G|j} = \Pr(\theta < \theta_j^* \mid j) = F_j(\theta_j^*), \tag{3}$$

where $F_j(\cdot)$ is the conditional cumulative distribution function of θ, i.e. conditional on the choice of car j. This distribution may differ across car makes j. For example, it is empirically observed that consumers who decide to purchase larger cars also tend to drive more miles per year. Since the cumulative distribution function $F_j(\cdot)$ is a monotone increasing function, we can invert (3) such that $\theta_j^* = F_j^{-1}(s_{G|j})$. Rearrange this using (2) to obtain:

$$F_j^{-1}(s_{G|j})\Delta\pi_j + \Delta\tau_j + \rho\Delta p_j = \Delta a_j, \tag{4}$$

where $F_j^{-1}(\cdot)$ is a monotone function defined as the inverse of $F_j(\cdot)$. Equation (4) is the transformed conditional demand equation. Before discussing its empirical specification, several remarks are in order.

First, note that the random variable ν_j does not appear in (4). In this sense our approach is distinct from the work of Berry, Levinsohn and Pakes (1995) and the subsequent literature. They focus on understanding the pattern of product differentiation between different cars, by explicitly modelling ν_j in a random coefficients framework. Our approach abstracts from the product differentiation aspects between cars, and instead focuses on understanding the choice of the engine variant, conditional on the choice of a car make, without specifying the distribution of ν_j.[18]

[18] It is also instructive to make a comparison with Bresnahan (1981, 1987), who made early contributions to measuring product differentiation and market power. He formulated a model of one-dimensional vertical product differentiation (with quality proxied by a combination of horsepower, car size, etc...). In our empirical model, there is also a single quality dimension (namely fuel expenditures per mile). However, Bresnahan's one-dimensional vertical differentiation model is used to describe product differentiation between different

Second, note that annual mileage is the only source of consumer heterogeneity affecting the conditional gasoline–diesel choice. The consumers' annual mileage matters since it is interacted with the fuel expenditures per mile π_{jk} associated with engine variant k of car j. In practice, consumers may also be heterogeneous in their valuation of other engine characteristics, such as horsepower. To account for such heterogeneity, one could specify an unconditional market share equation, and obtain identification of the random coefficients as in Berry, Levinsohn and Pakes (1995). Instead, we chose to start with the conditional market share equation and account for annual mileage as the main source of heterogeneity. To obtain an idea of the plausibility of this specification, we will compute the average mileages of gasoline and diesel consumers as predicted by the estimates, and confront these with the available prior evidence on annual gasoline and diesel mileage. If annual mileage is indeed the most important source of consumer heterogeneity affecting the gasoline–diesel choice, one can expect the predicted mileages for gasoline users to be substantially below the predicted mileages for diesel users, in line with the actually observed mileages. In contrast, if there are important other sources of heterogeneity, one may expect the actual mileages for gasoline and diesel users to be closer to each other than predicted by the demand model.

3.2 Specification

To estimate the demand, we use product-level data on aggregate sales, prices and characteristics, plus data on the mileage distribution. To complete the demand specification, we need to specify $F_j^{-1}(\cdot)$ and Δa_j in (4). First consider $F_j^{-1}(\cdot)$. Since $F_j^{-1}(\cdot)$ is the inverse of the cumulative distribution function of mileage, one can interpret $F_j^{-1}(s_{G|j})$ as a *threshold mileage*, i.e. the mileage that is not reached during one year by a given proportion $s_{G|j}$ of consumers purchasing j. In principle, this information can be obtained from consumer survey tables containing, for each make, one column with annual mileage categories and a second column with the proportion of cars corresponding to each mileage category; there is thus no need for making parametric assumptions on the distribution function of θ. In

cars. In contrast, our model only describes differentiation between different engine variants, given the car choice (while differentiation across cars is allowed to be more general).

practice, we do not have such a detailed information on mileage distribution at our disposal for the three countries. We therefore specify the cumulative distribution function of θ, and its corresponding inverse, parametrically as a parsimonious function of two parameters, the mean annual mileage μ_j and the standard deviation σ_j, for which we have prior information by several principal characteristics of the car makes, such as horsepower and weight. Given our parametric approach it is important to examine the robustness of our results with respect to various alternative distribution functions. We considered three different functional forms: the double exponential (which resembles the bell shape of the normal distribution), a two-parameter exponential (which is a skewed distribution function) and the uniform. The results are essentially robust with respect to these alternative specifcations. We report here only the results using the double exponential distribution. Applying (3), the market share equation $s_{G|j} = F_j(\theta_j^*)$ is then given:

$$s_{G|j} = \exp\left(-\exp\left(-\left(\theta_j^* - \mu_j\right)\frac{\pi}{\sqrt{6}\sigma_j} - \gamma\right)\right) \tag{5}$$

where $\pi \approx 3.14$ and $\gamma \approx .577$ is Euler's constant. It is straightforward to rearrange this equation to obtain a solution for $\theta_j^* = F_j^{-1}(s_{G|j})$. This solution can then be substituted into the transformed demand equation (4).

Now consider Δa_j. Recall that Δa_j captures the difference in the mean intrinsic utility from purchasing make j with a diesel engine (a_{jD}) or with a gasoline engine (a_{jG}). Note that the variables measuring size and safety are common to the gasoline and diesel variants of a make j, so that they do not enter Δa_j. Hence only the performance variables, such as horsepower, displacement, speed and acceleration, enter Δa_j. More precisely, we specify Δa_j as follows:

$$\Delta a_j = \alpha_0 + \alpha_1 \Delta PERF_j + \varepsilon_j, \tag{6}$$

where $\Delta PERF_j$ captures differences in observed performance variables, for example differences in horsepower. The constant α_0 can be interpreted as the mean extra utility from a diesel variant, possibly negative. It captures specific diesel features that are not measured by the performance variables in $\Delta PERF_j$, such as discomfort from noise, unreliability or longer durability. Finally, the term ε_j is a mean zero i.i.d. error term. It captures diesel features specific to make j that influence utility, but that are unobserved by the econometrician. For example, it is possible that a Renault 19 has a diesel engine with an above average reliability, whereas Volkswagen Polo has one below average.

To summarize, substituting the expression for Δa_j, (6), in equation (4), we obtain the following demand specification that can be taken to the data:

$$F_j^{-1}(s_{G|j})\Delta\pi_j + \Delta\tau_j + \rho\Delta p_j = \alpha_0 + \alpha_1 \Delta PERF_j + \varepsilon_j \tag{7}$$

where $F_j^{-1}(s_{G|j})$ can be computed from inverting the distribution function given by (5). The parameters to be estimated are α_0, α_1 and ρ. The required data are sales, prices, technical characteristics, and the mileage distribution across consumers.

4 Pricing

Because of our interest in the implications for price discrimination and tax incidence, we also specify two stylized models of pricing. As in the specification of the demand side, we are not interested in a complete analysis of pricing. Instead, we focus on explaining price *differentials* between diesel and gasoline cars. Generally speaking, the price differential Δp_j can be decomposed in a marginal cost difference Δc_j and a markup difference Δm_j, i.e.:

$$\Delta p_j = \Delta c_j + \Delta m_j$$

A first model states that there are no markup differences, $\Delta m_j = 0$. The price differential between diesel and gasoline cars is then entirely driven by differences in the marginal cost of producing diesel and gasoline cars. A purely cost-driven explanation for price differentials would obviously obtain under perfect competition. However, price differentials will also be cost-driven under imperfect competition if firms charge the same markup for their gasoline and diesel cars. Several theoretical models of oligopoly pricing in fact yield zero markup differences between high and low quality products of the same firm, see e.g. Gilbert and

Matutes (1993) and Armstrong and Vickers (2001).[19]

An alternative model states that the markup differences between diesel and gasoline cars are equal to the premium charged under monopoly market power. Specifically, consider a monopolist for car j, setting the price of its diesel variant p_{jD} to maximize the sum of its gasoline and diesel profits, given that consumers do not substitute to other cars:

$$(p_{jG} - c_{jG})\, s_{G/j} + (p_{jD} - c_{jD}) \left(1 - s_{G/j}\right),$$

where $s_{G/j} = F_j\left(\theta_j^*\right)$ is the conditional market share equation as given by (3). The optimal price p_{jD} satisfies the first-order condition:

$$-\left((p_{jG} - c_{jG}) - (p_{jD} - c_{jD})\right) f_j(\theta_j^*)\frac{\rho}{\Delta\pi_j} + 1 - F_j\left(\theta_j^*\right) = 0,$$

where $f_j(\cdot)$ is the density function of $F_j(\cdot)$. This can be rewritten as:

$$\Delta p_j = \Delta c_j + \frac{1 - F_j(\theta_j^*)}{f_j(\theta_j^*)}\left(\frac{-\Delta\pi_j}{\rho}\right).$$

A monopoly price surcharge for a diesel car would naturally result if the firms have local monopoly power for each make j.[20] Yet note that to obtain the above expression for price differentials it is sufficient to assume that the prices of the diesel variants, p_{jD}, are set monopolistically. This thus allows for the possibility that the price levels of base gasoline variants are set quite competitively.

Analogous to the specification of the mean utility difference between a gasoline and a diesel car, Δa_j, we specify the marginal cost difference Δc_j as follows:

$$\Delta c_j = \gamma_0 + \gamma_1 \Delta PERF_j + \eta_j. \tag{8}$$

[19]Gilbert and Matutes (1993) show this in an oligopoly with two price setting firms, each firm selling a high quality and a low quality variant of horizontally differentiated products. Armstrong and Vickers obtain a more general result in the context of nonlinear pricing (See their Proposition 5 of Armstrong and Vickers (2001)).

[20]Specify, for example, for each make j the individual-specific taste parameter ν_j to equal 0 for a fraction φ_j of consumers, and equal to $-\infty$ for the remaining fraction. For each car make j there is then local monopoly power over a fraction φ_j consumers.

The same characteristics that influence the differences in the mean utility may thus also affect differences in marginal costs.

To summarize, we have two possible pricing specifications, which we will refer to below as our "competitive" and "monopolistic" pricing specifications:

$$
\begin{aligned}
\text{“competitive”} &: \quad \Delta p_j = \gamma_0 + \gamma_1 \Delta PERF_j + \eta_j \qquad (9)\\
\text{“monopolistic”} &: \quad \Delta p_j - \frac{1 - F_j(\theta_j^*)}{\rho f_j(\theta_j^*)}(-\Delta \pi_j) = \gamma_0 + \gamma_1 \Delta PERF_j + \eta_j .
\end{aligned}
$$

One should keep in mind that these terms only serve to label the pattern of observed price *differentials* between gasoline and diesel variants. They do not necessarily refer to the manufacturers' actual pricing behavior for all prices in the market.

5 Identification and estimation

In the empirical analysis we begin by estimating the demand equation (7) separately, without imposing any structure on pricing behavior. Next, we estimate the demand equation (7) jointly with the pricing equation (9). Whether or not one estimates the equations simultaneously, it is important account for the fact that $s_{G|j}$ and Δp_j are endogenous variables, simultaneously determined by consumer demand and manufacturer pricing. Consequently, one may expect these variables to be correlated to the error terms ε_j and η_j, which capture the unobserved diesel features of model j, influencing utility and marginal cost. For example, a diesel variant of a car j with a particularly high unobserved diesel quality ε_j will have a high market share, but at the same time the manufacturers will presumably charge a high price. The result is a positive correlation between Δp_j and ε_j. A simple ordinary least squares estimator would therefore be inconsistent; in particular, ρ would be biased towards zero. Consequently, instrumental variables should be used to obtain consistent parameter estimates. More specifically, we adopt Hansen's (1982) generalized method of moments (GMM). This estimator can be used for estimating a single equation or a simultaneous system with possibly correlated error terms ε_j and η_j. The estimator allows one to compute heteroskedasticity-consistent standard errors that are robust with respect to serial correlation.

It remains to specify the set of instruments, which constitute the orthogonality conditions of the GMM estimator. The instruments should be exogenous variables, uncorrelated to the error term. Our main identification assumption is that the nonprice characteristics of the cars, such as performance, fuel efficiency or taxes, qualify as such variables. This is a common assumption made in the empirical literature on oligopoly models with product differentiation. The usual justification for this assumption is that these are variables that can only be slowly adjusted, so that they may be viewed as predetermined at the pricing stage. The typical difficulty in adopting this approach is that these variables may enter *both* the demand and supply (cost) side, so that there may not be a sufficient number of instruments for the number of parameters to be estimated. Berry (1994) and Berry, Levinsohn and Pakes (1995) discuss this problem and propose to use (functions of) the characteristics of the competitors as additional instruments. In our application, the parameter restrictions that are implicit in specification (7) provide another answer to the suitable choice of instruments. In particular, the variables $\Delta\pi_j$ and $\Delta\tau_j$ can be used as instruments for Δp_j. Identification follows from the fact that fuel costs and taxes are monetary variables that influence the consumers' budget constraint (and indirect utility) in the same manner as prices, for which they instrument. In sum, using $\Delta PERF_j$, $\Delta\pi_j$ and $\Delta\tau_j$, we have one more instrument than the number of parameters to be estimated.

6 The empirical results

As described in more detail in section 2, our data set contains sales, list prices and technical characteristics of 41 pairs of automobile models in three European countries, Belgium, France and Italy, during 1991-1994, plus data on the distribution of mileage across consumers. In the discussion below the subscript j should now be viewed as indexing the car make, country and year (instead of only the car make). To estimate (7) and (9), we need to specify the technical characteristics entering in $\Delta PERF_j$. We have data on the following performance variables: horsepower, displacement, weight, speed and acceleration. We experimented with several alternative specifications. The empirical results presented in Tables 4 to 6 are based on a specification including the horsepower, displacement, and weight. The parameter estimates, and the implications for the decomposition of price differentials into cost and markup differences, and for tax incidence, were robust when other characteristics were included. For example, we considered a specification with the horsepower/weight ratio and displacement as characteristics. We also considered a specification in which speed and acceleration enter instead of horsepower and displacement; and a specification in which horsepower, displacement, weight, speed and acceleration all enter together.

We impose some further structure on the error terms ε_j and η_j through fixed effects. We include market dummies for France and Italy to capture possible differences in tastes and costs, relative to the reference country Belgium. We cannot *a priori* rule out the possibility that French and Italian consumers have different tastes for gasoline versus diesel cars than Belgian consumers. Significant cost differences across markets, in contrast, seem rather unlikely: there is no reason to expect a systematically higher cost of selling a diesel car in the French market than in the Belgian or Italian market. Insignificant estimates for the market dummies on the cost side may thus be expected if the econometric model is well specified. We also include source country dummies for French, German or Italian cars to capture taste and cost differences across source countries. The reference is "other countries", i.e. Japan, Spain or the United Kingdom.

6.1 Demand

We start by estimating the demand equation separately. Column 1 of Table 4 shows the results. The parameters of the technical characteristics have the expected positive sign; for displacement and weight they are significant. Since diesel cars on average have a lower horsepower, but a higher weight and displacement than gasoline cars, it is interesting to look at the overall valuation differences implied by the estimates (Δa_j). It turns out that Δa_j is small on average, namely -291\$ (written in capitalized terms), compared to an average purchase price differential of 2323\$ (Table 1B). This confirms the discussion in section 2:

firms are relatively succesful in offering "twin" gasoline and diesel cars, which are comparable in overall performance even if the individual characteristics differ because of technological constraints.

The price coefficient (ρ) is estimated very precisely at 0.121. Recall that ρ may be interpreted as an annualization coefficient, reflecting the extent to which consumers take into account the purchase price of the car in their annual budget constraint. Assuming a vehicle life of 11 years, the consumers' implicit interest rate implied by the estimate of ρ is about 11.5 percent. This is slightly above (though not significantly different from) the actual interest rates on the capital markets during the period 1991-1994. For example, the 5 year government bond interest rate varied between 7.5 and 10 percent, whereas the interest rates on installment loans specifically for purchasing cars varied between 9 and 11.7 percent in Belgium.[21] Consumers thus tend to solve their investment problem in a rather forward looking way: they use interest rates close to the capital market rates when trading off the higher initial purchase price for a diesel car against the future fuel cost savings.[22]

The demand intercept is estimated to be -325.9 and significant: this says that Belgian consumers (the reference market) value diesel cars over 300 dollar less than a gasoline car, after controlling for the observed differences in characteristics; this may be due to, for example, discomfort from noise or lower reliability. This negative diesel valuation is somewhat stronger in France (-50 dollar); in Italy, consumers seem to care less about diesel comfort *per se* (significant fixed effect of about $+150$ dollar). The dummy variables for the source countries are all insignificant, implying that the French, German and Italian diesel brands do not have a significantly higher valuation than the brands from other origins.

[21]This rate concerns a value of an installement loan of BEF 400000, or about $10000, with fixed monthly installments during 48 months (information provided by consumer magazine Test-Achats).

[22]This is consistent with economic theory, but conflicts with some anomalies in the literature. For example, Hausman (1979) finds econometric evidence that consumers use too high interest rates when choosing among airconditioners. Loewenstein and Thaler (1989) report experimental evidence on myopic consumer behavior. An explanation for the result that consumers use the "right" implicit interest rate is that there are good financing possibilities for cars, and that the gasoline/diesel choice is a fairly clean investment problem, since every car typically offers both engine versions.

What does the demand specification predict about the annual mileage driven by consumers of gasoline and diesel cars? An answer to this question can provide an idea of how well the demand model is specified. As discussed above, if the sole source of heterogeneity regarding the gasoline/diesel decision is the consumers' annual mileage, then one would expect the average annual mileage of gasoline consumers to be considerably lower than the average annual mileage of diesel consumers. In contrast, if there are other important sources of consumer heterogeneity, uncorrelated with mileage, then one would expect the average annual mileage of gasoline and diesel consumers to be closer to each other than predicted by the demand specification.

To address this question, we use data on the actual average mileages, distinguished by gasoline and diesel consumers, for several car categories in the Belgian market. We confront these data with the average mileages as predicted by the model; for example, the predicted average mileage by gasoline consumers of car j is numerically computed by $\int_{\theta \leq \theta_j^*} \theta f_j(\theta) d\theta / F_j(\theta_j^*)$. Standard errors and 95 percent confidence intervals are computed using a parametric bootstrap procedure.[23] The results are shown in Table 5. For both gasoline and diesel consumers, the predicted mileages show a pattern in line with the actual mileages. For gasoline consumers, the mileages vary between 13000 km and 16000 km, depending on the weight category of the car; for diesel consumers they vary between 21000 km and 25000 km. In 10 of the 12 cases, the actual gasoline or diesel mileages fall within the 95 percent confidence interval associated with the predictions of the model (these cases are indicated by an asterix). These findings are evidence that mileage heterogeneity is indeed a driving force in explaining the consumer gasoline/diesel demand. If other factors would also be significant, then one would expect significant underpredictions for gasoline mileages and overpredictions for the diesel mileages. Why is mileage heterogeneity in fact so important in the purchasing decision? We already provided institutional evidence in Section 2 that consumers are to a large extent guided by fuel cost savings in their choice of engine type.

[23]Specifically, we assume that the estimated parameters are the true means and that the estimated variance covariance matrix of the parameters is the true variance covariance matrix. We then take 2000 random draws of the parameters assuming a multivariate normal distribution.

This is in part the result of succesful new product developments, leading to the supply of a range of closely comparable "twin" gasoline/diesel models. Furthermore, even if other characteristics, such as performance differences, play an important role, it is possible that the consumers' idiosyncratic valuations for these characteristics are correlated with their mileage.

6.2 Pricing

We next estimate the demand equation (7) and the pricing equation (9) jointly. A central question is whether the price differentials between gasoline and diesel cars are largely driven by cost differentials, or whether monopolistic price discrimination is important. To distinguish between the two alternative pricing models in (9), we considered nonnested hypothesis tests. More specifically, as in Feenstra and Levinsohn (1995) we use the instrumental variable version of the P-test procedure proposed by McKinnon, White and Davidson (1983) in the context of instrumental variables.[24] The P-test statistic compares pairs of models and asymptotically has a standard normal distribution, if the null hypothesis is correct. The t-statistic for the validity of the monopolistic model against the alternative competitive model equals 0.328, well below the critical value (at a 95% confidence level) of 1.96. In contrast, the t-statistic for the validity of the competitive model against the monopolistic alternative is large, i.e. 6.672. These test statistics tell us that the model of monopolistic markup differences cannot be rejected in favor of the competitive model, while the reverse is clearly possible. Recall from section 4 that one should not conclude that *all* prices are necessarily set monopolistically in the automobile market. The results relate only to the pattern of price *differentials* between gasoline and diesel cars.

To gain a further understanding on the presence of monopolistic price discrimination, we also estimated the following equation:

$$\Delta p_j - \lambda \frac{1 - F_j(\theta_j^*)}{\rho f_j(\theta_j^*)}(-\Delta \pi_j) = \gamma_0 + \gamma_1 \Delta PERF_j + \eta_j$$

[24]The test applies to linear, single equation models. We therefore apply the test on the pricing equation, which is linear, using the estimated value of ρ from the demand equation.

jointly with the demand equation. This equation nests the two forms of pricing in (9) as special cases through the parameter λ. The estimate of λ is about 0.913, with a standard error of about 0.120. This confirms that price differentials are much closer to (and insignificantly different from) monopolistic pricing than to competitive pricing.

Perhaps the most convincing evidence in favor of monopolistic price discrimination is provided by the obtained demand and cost parameter estimates under the alternative specifications. Columns 2 and 3 show the parameter estimates under joint estimation of the demand and pricing specifications. All demand parameter estimates in the monopolistic specification (column 2) are comparable to the ones obtained from estimating the demand equation separately (column 1). This indicates that adding the monopolistic pricing specification does not seriously affect the demand side parameters. In contrast, several demand parameters change substantially under the competitive specification. This is for example true for the coefficient on weight and several market and source fixed effects. The most drastic change is the estimate of the annualization coefficient ρ, which doubles in size and has a very small standard error.

The cost side parameters are consistent with *a priori* expections in the monopolistic specification, but not always in the competitive specification. The technical characteristics positively and significantly affect marginal costs under the monopolistic specification; in the competitive specification, the sign of the horsepower parameter is negative (though insignificant). The market fixed effects show the most interesting differences. In the monopolistic specification, the fixed effects for the French and Italian market (relative to Belgium) are insignificant, which implies that there are no significant cost differences across markets. In contrast, in the competitive specification the market fixed effects do enter significantly, with a significantly positive and large fixed effect for France, and a significantly negative fixed effect for Italy. This follows from the fact that the competitive specification imposes zero markup differences between gasoline and diesel cars; any systematic cross-country differences in the price surcharge for diesel cars must then be attributed exclusively to cost differences. In the monopolistic specification, cross-country differences in the diesel surcharge may also be the result of markup differences. If one accepts the presumption that marginal cost differences between gasoline and diesel cars should not differ significantly across markets, these findings may be viewed as further economic evidence in favor of monopolistic price differences.

6.3 Explaining price differentials

Table 6 uses the results from the preferred monopolistic specification in Table 4 (column 2) to decompose the observed price differences between gasoline and diesel cars into cost and markup differences. In particular, for each make j, I compute the fraction of the price difference Δp_j that is explained by the difference in markup. The first two columns of Table 6 present the average fraction across makes and the standard deviation over the sample. Since markups are a function of the parameter estimates, the fractions are themselves estimates. To have an idea of the precision of this estimate, the third and fourth column show the estimated fraction for a representive make (i.e. with average characteristics) and its corresponding standard error.[25]

The first part of Table 6 considers all car makes in the sample. On average, the pricing model attributes about 84 percent of price differences to markup differences. The standard deviation is relatively large, 47 percent, which shows that for specific cars the estimated fraction may be much lower or higher. For a representative make (with average characteristics) the fraction of the price difference that is explained by the markup difference is estimated fairly precisely at 61 percent.

The second part of Table 6 splits up the samples by country. This yields some interesting further insights. Markup differences especially contribute to price differences in France, and less so in Belgium and in Italy. This follows from the fact that France has the most favorable tax treatment of diesel cars (as discussed in detail in Section 2), thereby providing the strongest incentives for price discrimination. Notice that the greater importance of markup differences in France than elsewhere is also consistent with the estimates in Table 4, which showed that cost differences between diesel and gasoline cars do not vary significantly

[25]The standard error is obtained by first linearizing the expression for the estimated markup fraction around the parameter estimates, and then applying the standard formula for computing the standard error of linear transformations of random variables.

across markets. In this case, then the larger diesel price premium in France than in Belgium and Italy (see Table 2) must naturally follow from higher diesel markups.

To further verify the plausibility of the results on the relative importance of cost versus markup differences, it would be instructive to have some prior information on cost differences. Unfortunately, no direct information was at our disposal. As an alternative, we collected data on the wholesale prices for a sample of gasoline and diesel *engines*, as charged to the dealers when old or broken engines need replacement. We compare the differences between the diesel and gasoline engine prices with the respective car price differences.[26] Engine price differentials may be a reasonable proxy for differences in the cost of producing gasoline and diesel cars, provided that the manufacturers do not also use the wholesale prices to price discriminate. Interestingly, we find that the average engine price differential over the sample of car makes is 586 dollar, compared to a much larger average car price differential of 1567 dollar, even though the cars differ in nothing else than the engine.[27] This confirms that the empirical results that price differentials are to a large extent driven by markup differentials.

6.4 Implications for tax incidence

Further insights in how consumers and manufacturers behave in response to taxes is obtained from computing various elasticities of demand with respect to tax changes. We consider the effects of both changes in fuel taxes and changes in annual car taxes on the market share of gasoline cars in the total sales of a make j. We concentrate on conditional effects, i.e. conditional on the consumers' choice of a given car make. A more complete analysis of tax

[26]The engine price data were collected directly from Belgian dealers in 2001, for the models in our original data set, or for their successors in case the models no longer were sold. For a consistent comparison, we also collected the corresponding car price data for this sample of models.

[27]More precisely, for the sample of models in Belgium/2001 the average gasoline engine price was 4118 dollar, compared to an average diesel engine price of 4704. The average gasoline car price was 18581 dollar, versus an average diesel car price of 20149. The car price data are of a comparable order of magnitude as the Belgian car price data during 1991-1994 (see Table 2), while the characteristics data were also comparable (average gasoline displacement of 1626cc versus average diesel displacement of 1928; average gasoline horsepower of 75.86kW versus average diesel horsepower of 67.89kW)

effects would also look at substitution towards different car makes, or to other modes of transportation. Such an analysis would be very interesting for policy, yet it is beyond the scope of this paper. It would require a more detailed analysis of the market, with specific assumptions on product differentiation between cars (ν_j, e.g. specified as in Berry, Levinsohn and Pakes (1995)) and on competition between firms.

There are several ways to present the tax elasticities. For example, one may look at the separate demand effects of increasing the annual car tax for gasoline and for diesel cars. To summarize the information, we decided to "average" these effects: we focus on the effects of increasing the fuel and car tax *differentials*. More specifically, we compute the effect on the market share of gasoline cars in the total sales of make j, when the gasoline fuel tax is increased by 0.5 percent and the diesel car tax is reduced by 0.5 percent; and similarly for the gasoline and diesel car taxes. The computed elasticities per make j are:

$$\begin{aligned}\varepsilon_j^F &= \frac{1}{2}\frac{\mathrm{d}s_{G|j}}{\mathrm{d}q_G}\frac{q_G}{s_{G|j}} - \frac{1}{2}\frac{\mathrm{d}s_{G|j}}{\mathrm{d}q_D}\frac{q_D}{s_{G|j}} \\ \varepsilon_j^C &= \frac{1}{2}\frac{\mathrm{d}s_{G|j}}{\mathrm{d}\tau_{jG}}\frac{\tau_{jG}}{s_{G|j}} - \frac{1}{2}\frac{\mathrm{d}s_{G|j}}{\mathrm{d}\tau_{jD}}\frac{\tau_{jD}}{s_{G|j}}.\end{aligned}$$

The term ε_j^F reads as the elasticity of the demand for car j's gasoline powered variant with respect to the fuel tax differential; ε_j^C is the elasticity of the demand for car j's gasoline powered variant with respect to the car tax differential.

We compute both *partial* and *full* tax elasticities. The partial tax elasticities are those one traditionally obtains from estimating demand equations, i.e. they account for the effects of taxes on demand, holding all other things constant. The full tax elasticities take into account simultaneous changes in the manufacturers' prices. Our previous estimates favored a specification in which there is tax incidence in the following sense: the manufacturers respond to a more favorable diesel tax treatment by raising their markups (and vice versa). But it is not yet clear to which extent this tax incidence is driven by fuel taxes or by car taxes. A comparison between the various partial and full tax elasticities can shed light on this question.

Before presenting the estimates, two caveats are in order. First, recall that the empirical model assumed that consumers have an inelastic demand for mileage. The estimated elasticities thus do not take into account changes in driving habits. If an elastic mileage demand would be assumed, our estimated elasticities may change. Nevertheless, the empirical literature referred to in the introduction has obtained small elasticity estimates for the demand for mileage (conditional upon car purchase), ranging between 0 and 0.2. Our results would thus essentially remain robust. Second, the model assumes that the product characteristics remain unchanged. In the long run, firms may invest in modifying their products in response to fuel price changes. Pakes et al. (1993) show that companies started to introduce new cars in the U.S. after the increased fuel prices in the 70s; the development of reliable diesel cars in Europe during the 70s and 80s has a similar interpretation. Yet note that the European countries currently set the fuel and car taxes in an uncoordinated way (unlike VAT); a national tax reform may therefore only have a modest impact on the product characteristics. Even if product characteristics would be modified in the long run, this would alter the level of the elasticities, yet our main conclusion that one should account for the mitigating effects of tax incidence (price responses) would remain.

Table 7 presents the estimates. We focus the presentation on the estimated elasticity of a representative car (with average characteristics). The standard error is computed numerically using the same procedure described in the previous subsection. First, consider the estimated partial elasticities, ignoring tax incidence. Looking at a representative car for the three countries, one can see that increasing the fuel tax differential has a much larger effect on demand than increasing the car tax differential (elasticity of -2.78 compared to -.597). This is because the annual car taxes are much lower in absolute value than the annual fuel costs (expenditure share of less than 25 percent), so a percentage increase in car taxes has a smaller effect on the consumer's budget constraint than a percentage increase in fuel costs. The high fuel tax elasticity is consistent with the high *long-term* fuel price elasticities obtained in the transportation and energy literature, as discussed in the introduction. Notice that Italy has much lower fuel and car tax elasticities for its representative car, as compared to the other two countries. This follows from the high market share of the representative gasoline car in Italy, caused by the disfavorable diesel tax treatment.

Now consider the estimated full elasticities, which take into account the manufacturers' tax incidence. This shows a quite different picture. The car tax and especially the fuel tax elasticity are now substantially lower than when tax incidence is ignored. The manufacturers absorb an important part of an increase in the tax differential by lowering their price differential. The drop in the elasticities follows from our earlier obtained finding that markups explain an important part of the price differences between gasoline and diesel cars. An interesting new finding also emerges from our estimates: the fuel tax elasticities drop by more than the car tax elasticities when tax incidence is taken into account. This shows that most of the tax incidence is based on the fuel taxes and less so on the car taxes. This is also consistent with the reduced form findings in Table 3, which showed that car taxes have a lower impact on manufacturer's price differentials than fuel taxes. Economically speaking, fuel taxes provide the main basis for price discrimination, allowing the manufacturers to exploit consumers' mileage heterogeneity. Notice that the drop in tax elasticities is most pronounced for France: this is the country with the most favorable tax treatment and the largest resulting markup differences between gasoline and diesel cars.

The estimates of the elasticities have implications for tax policy. We illustrate this using two examples.

Effectiveness of tax policy

In designing a public policy towards cars, the U.S. and Europe have followed a quite different approach. The U.S. have put most emphasis on direct regulation of the car purchasing decision. This has been implemented for example through fuel efficiency standards (the CAFE standard), through purchasing mandates for fleet owners, and through mandated changes in auto and fuel availability. In Europe, car and fuel taxes have been used more commonly as an instrument to direct the demand towards a specific type of cars. The differential gasoline and diesel tax policy is not the only example of this approach. Another example is the substantial tax discrimination between leaded and unleaded gasoline cars to promote the purchase of unleaded cars. In the near future, the introduction of electrical cars may again raise the tax question. At first sight, our high estimates of the *partial* elasticities indicate that a tax policy can be a quite effective policy instrument. This is also suggested by the high long-term fuel price elasticities in the transportation/energy literature, and Borenstein's (1993) finding for U.S. data on leaded and unleaded gasoline cars. However, our results on the *full* elasticities demonstrate that it is important to properly take into account the manufacturers' pricing responses when evaluating the effect of a change in taxes on demand. In the case of gasoline and diesel fuel taxes, a proper account for tax incidence may substantially reduce the estimated effectiveness of a tax policy.

Revenue implications of reducing tax discrimination

A central theme in the European policy debate is whether the current system of tax discrimination should be maintained. From an environmental point of view, there are several opponents against the tax discrimination because of the adverse effects of the diesel fuel (see Section 2). From a distributional point of view, specific consumer interest groups have (unsuccessfully) taken action to reduce the discrimination in car taxes, based on constitutional arguments. Whatever the possible policy objectives behind the recent political pressure to reduce tax discrimination, one may ask what would be the budgetary implications for the governments. If there were only one good to be taxed, this question would be easily addressed by looking at the tax elasticities: after a tax increase revenues would increase if and only if the elasticity (in absolute value) were less than one. In our application there are two goods, gasoline and diesel cars, which may be taxed either directly, through the annual car tax, or indirectly, through the fuel taxes. In this case, the tax elasticities are again important, but one should also account for the fact that a loss of consumers for one good implies a gain in consumers for the other good.[28]

Consider for example an increase in the diesel car tax by 1 unit. On the one hand, this directly raises tax revenues proportional to the market share of diesel cars. On the other hand, this induces substitution from diesel cars to gasoline cars. The magnitude of this substitution effect is proportional to the difference in tax revenues from gasoline and diesel cars, as paid by the indifferent consumer. If the indifferent consumer would pay a higher amount of car plus fuel taxes on a gasoline than on a diesel car, then the substitution effect is

[28]We maintain the approach of looking at susbtitution between gasoline and diesel cars, conditional on the choice of a specific make.

positive and reinforces the direct effect on revenues. If, in contrast, the indifferent consumer would pay a lower amount of car and fuel taxes on a gasoline car, then the substitution effect is negative and may even outweigh the direct revenue effect.

Table 8 presents the revenue effects of various tax experiments for a representative car make, expressed in elasticity form.[29] To interpret the results, notice first that in all three countries the indifferent consumer of the representative car would pay higher taxes if she would choose the gasoline engine instead of the diesel engine. When purchasing a gasoline engine, her extra annual tax payment (fuel taxes plus car tax) would amount to \$282 in Belgium, \$378 in France and \$155 in Italy. Our previous discussion thus implies that the revenue effects from raising the diesel taxes (fuel or car taxes) will necessarily be positive (since it induces revenue-raising substitution to gasoline cars), while the revenue effects from raising gasoline taxes are ambiguous.

First, consider the effects of raising the diesel taxes (the second and fourth columns of Table 8). In Belgium and France, the revenue effect of raising the diesel fuel taxes are quite substantial, with elasticities of respectively .62 and and 1.00 if one ignores tax incidence; and elasticities of .44 and .61 if one takes tax incidence into account. The revenue effects of raising the diesel car taxes are smaller (e.g., .25 and .13 if one accounts for tax incidence), but this follows from the relatively small revenue share of car taxes relative to fuel taxes (less than 25 percent). In Italy, the revenue effects of fuel and car taxes are much smaller than in Belgium or France, for two reasons: (i) the lower substitution effects found in Table 7, and (ii) the lower extra amount of taxes paid by the indifferent gasoline consumer, which reduces the budgetary impact arising from the substitution effect.

Now consider the revenue effects of raising gasoline taxes (the first and third columns in Table 8). As expected, the effects are no longer necessarily positive. In Belgium and especially in France, a raise in the gasoline fuel tax would *reduce* tax revenues if tax incidence

[29] More specifically, to evaluate the revenue effects of the gasoline car tax, we compute $(\mathrm{d}R_j/\mathrm{d}\tau_{jG})/(\tau_{jG}/(R_j)$, where R_j is the total tax revenue on car make j. This expression thus measures the effect of a 1 percent car tax increase on car j's total tax revenues (conditional on the purchase of car j). Analogous formulas apply for the other tax effects.

is ignored. However, a raise in the gasoline fuel tax would still (moderately) *increase* tax revenues, if one takes into account that the manufacturers will respond by lowering the price of gasoline cars. Indeed, if one accounts for tax incidence, the estimated substitution effect towards diesel cars, which is bad for revenues, is much lower (see Table 7). In Italy, the revenue effects of a raise in the gasoline fuel tax are positive and strong, also due to the weak substitution effects found in Table 7. Finally, the revenue effects of a raise in the gasoline car taxes are small in all countries. This largely follows from the small share of car taxes in total revenue.

To illustrate how to use these numbers in practice, consider a policy to reduce the fuel tax discrimination by raising the diesel fuel tax. As discussed, this policy has been advocated by many in the European policy debate, motivated by environmental and/or distributional considerations. Table 8 implies that such a policy would not contradict with government budgetary restrictions; it would rather soften the government's budget constraint. Especially in Belgium and in France the tax revenues would increase quite substantially. Put differently, the current favorable tax treatment on the diesel fuel in Europe is hard to defend on budgetary considerations. Since distributional or environmental goals would also favor an increase in the diesel fuel tax, other objectives, such as subsidization of the transportation sector, should explain the current tax system.

7 Conclusion

The existing tax policies towards gasoline and diesel cars in European countries provide a unique opportunity to analyze quality-based price discrimination and the implied tax incidence. We have developed an econometric framework of demand and pricing for gasoline and diesel cars. Consumers make a decision to buy a gasoline or a diesel car based on their annual mileage. Manufacturers set gasoline and diesel car prices with the possible aim of discriminating between consumers with a high willingnes to pay for savings in mileage costs, and those with a low willingness to pay.

Our empirical results showed that the relative pricing of gasoline and diesel cars is consistent with price discrimination of a monopolistic type, and inconsistent with competitive price differentials. On average, about 75 to 90 percent of the price differentials between gasoline and diesel cars can be explained by markup differences. The substantial degree of quality-based, second-degree price discrimination may seem surprising in a market with many car manufacturers. It adds to the well documented evidence of geographically oriented, third-degree price discrimination in the European car markets.

The implied tax incidence is especially based on fuel taxes and less so on annual car taxes. This result has important implications for measuring the demand effects of increases in the fuel tax differentials between gasoline and diesel cars. If one accounts for the presence of tax incidence, the estimated effectiveness of a change in fuel taxes drops considerably, by more than 50 percent. An increase in diesel fuel and car taxes would unambiguously raise government revenues, whereas an increase in gasoline taxes may have ambiguous effects.

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9 Tables

Table1A. Summary statistics (406 observations)

	gasoline cars		diesel cars	
	Mean	Std Dev	Mean	Std Dev
horsepower (kW)	65.88	20.94	59.08	17.29
displacement (cc)	1605	323	1963	342
weight (kg)	1061	203	1143	206
speed (km/hour)	177.7	17.9	169.6	16.4
acceleration (sec. to 100 km/h)	13.24	2.44	15.21	2.50
fuel efficiency (liter per 100 km)	7.56	1.05	6.05	.76
French origin	0.160	0.367	–	–
German origin*	0.431	0.496	–	–
Italian origin	0.305	0.461	–	–
initial purchase price (in $)	18093	7061	20417	8063
fuel price (in $ per liter)	.931	.109	.712	.086
annual car tax (in $)	173.7	78.7	285.9	236.5
sales	19033	35885	9399	14689

* Includes G.M. (Opel) and Ford cars produced in Germany.

Table1B. Summary statistics, diesel – gasoline* (406 observations)

	Mean	Std Dev**		
		Overall	Between	Within
Δ horsepower (kW)	-6.80	7.36	7.29	1.84
Δ displacement (cc)	357	243	240	36
Δ weight (kg)	82	34	32	12
Δ speed (km/hour)	-7.11	6.75	6.58	1.84
Δ acceleration (sec. to 100 km/h)	-1.95	1.57	1.54	.32
Δ fuel efficiency (liter per 100 km)	-1.50	.67	.65	.12
Δ initial purchase price (in $)	2323	1632	1466	683
Δ fuel price (in $ per liter)	-.218	.051	.010	.050
Δ annual car tax (in $)	112.2	235.2	72.7	225.5
diesel sales/total sales	.419	.223	.144	.171

* Variables refer to absolute differences between the diesel and gasoline variables, except for sales, which refers to a percentage (comform with the model specification).

** The standard deviation is computed on the mean of the variables across time, say x_{jm}, where j indexes the car make and m indexes the market. The standard deviation of x_{jm} is decomposed into a between component $(\bar{x}_j - \bar{x})$ and a within $(x_{jm} - \bar{x}_j)$ component.

Table 2. Prices and taxes by country

(in $)	gasoline cars	diesel cars	difference
*Average annual fuel costs, including fuel taxes**			
Belgium	1130	739	-391
France	1188	679	-509
Italy	1090	670	-420
Average annual car taxes			
Belgium	218	284	66
France	126	86	-40
Italy	182	675	493
Average initial purchase price			
Belgium	17455	19585	2130
France	18216	20950	2734
Italy	19072	20973	1901
Diesel sales (in percent)			
Belgium			0.442
France			0.537
Italy			0.152

Table 3. Reduced form regressions

	OLS estimates	
constant	-2154.7	-3344.7
	(408.1)	(797.5)
French market	-88.2	-333.0
	(223.6)	(223.6)
Italian market	-1268.6	-2020.9
	(532.6)	(552.5)
French origin	38.5	-41.7
	(290.1)	(283.1)
German origin	459.1	364.4
	(256.7)	(251.2)
Italian origin	362.8	297.1
	(261.1)	(254.9)
horsepower	22.06	30.18
	(9.87)	(9.76)
displacement	2.78	2.62
	(.41)	(.40)
weight	8.01	6.43
	(2.08)	(2.05)
fuel cost	-6.34	-15.05
	(.73)	(3.29)
fuel cost*fuel cost		-.011
		(.003)
car tax	.56	-3.09
	(1.17)	(1.40)
car tax*car tax		.010
		(.002)
R^2	.344	.382

*Annual fuel costs are computed for the average driver by model.

Table 4. Estimates of (7) and (9)

	demand parameters		
	demand only	demand + pricing jointly	
		monopolistic	competitive
constant	-325.9	-308.5	-279.2
	(62.1)	(72.3)	(79.5)
French market	-49.8	-50.4	3.6
	(26.7)	(31.5)	(34.0)
Italian market	152.3	146.5	74.4
	(41.6)	(47.7)	(52.0)
French origin	43.0	50.9	96.1
	(36.9)	(42.4)	(46.8)
German origin	37.6	44.0	103.2
	(35.7)	(40.7)	(44.3)
Italian origin	60.0	65.9	136.7
	(32.8)	(38.0)	(41.5)
horsepower	1.86	1.80	.57
	(1.74)	(2.05)	(2.29)
displacement	.426	.420	.621
	(093)	(.111)	(.121)
weight	.845	.879	1.602
	(.386)	(.439)	(.471)
ρ	.121	.132	.250
	(.021)	(.022)	(.012)

(Table 4 continued on next page.)

Table 4. (Continued)

	demand + pricing jointly	
	monopolistic	competitive
	cost parameters	
constant	-1526.2	346.6
	(513.1)	(379.5)
French market	-13.1	535.2
	(235.5)	(179.1)
Italian market	-232.4	-914.7
	(273.6)	(239.7)
French origin	-355.2	426.6
	(433.6)	(242.9)
German origin	343.7	554.9
	(258.7)	(227.9)
Italian origin	265.4	550.2
	(273.6)	(223.0)
horsepower	24.0	–9.6
	(12.8)	(10.7)
displacement	2.83	1.15
	(.66)	(.56)
weight	7.90	6.60
	(3.14)	(2.27)

Standard errors are in parentheses.

Table 5. Actual mileages and mileages predicted by demand model (7)

Weight Category (in kg)	Average annual mileages					
	Gasoline Consumers			Diesel Consumers		
	Predicted	Std Dev	Actual	Predicted	Std Dev	Actual
650-750	12980*	524	13501	22497*	1669	25471
750-850	12771*	654	13583	20807*	1322	22217
850-950	12959	598	15019	20923*	1077	22984
950-1050	14331*	527	15101	25474*	1414	23667
1050-1150	12968	1178	15667	21144*	1420	23295
1150-1250	15052*	749	15344	24184*	1320	25038

* An asterix denotes cases where the actual value falls within the 95 percent confidence interval of the predicted value.

Table 6. Fraction of price differences explained by markups

	Mean	Std Dev	Representative Model	
			estimate	st. error
all countries	.840	.474	.612	.112
Belgium	.807	.487	.564	.124
France	.894	.372	.873	.132
Italy	.784	.627	.512	.112

Table 7. Elasticities of demand with respect to taxes

	Fuel taxes		Car taxes	
	estimate*	st. err.	estimate*	st. err.
	Ignoring tax incidence			
all countries	-2.783	(.260)	-.597	(.086)
Belgium	-3.103	(.305)	-.736	(.111)
France	-3.964	(.287)	-.569	(.084)
Italy	-.404	(.049)	-.091	(.014)
	Accounting for tax incidence			
all countries	-1.218	(.016)	-.465	(.048)
Belgium	-1.412	(.004)	-.583	(.064)
France	-.225	(.029)	-.280	(.084)
Italy	-.323	(.036)	-.090	(.013)

* The elasticity estimates are for a representative model.

Table 8. Revenue effects of various taxes*

	Fuel taxes		Car taxes	
	gasoline	diesel	gasoline	diesel
	Ignoring tax incidence			
all countries	-.109	.627	.026	.272
Belgium	-.109	.618	.033	.287
France	-.518	.996	-.067	.178
Italy	.702	.073	.174	.045
	Accounting for tax incidence			
all countries	.213	.444	.048	.236
Belgium	.191	.437	.060	.250
France	.224	.607	-.001	.130
Italy	.713	.067	.174	.045

* Elasticities for a representative model.